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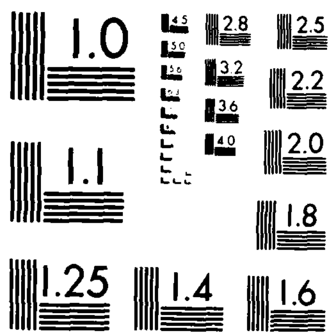

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K-PULSE FOR A THIN CIRCULAR LOOP

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Based on the pole-elimination concept, a time-limited input waveform, the K-pulse, is obtained for a thin conducting circular loop. The resultant response waveforms are also found to be time-limited. Therefore, by employing the K-pulse input waveform, the resonant ringing associated with the circular loop has been eliminated. The concept and procedure for deriving the K-pulse are discussed in this paper.

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K-PULSE FOR A THIN CIRCULAR LOOP

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I. INTRODUCTION

It was pointed out [1] that it is useful and proper to model or simulate the target responses at N aspect and polarizations by a linear distributed parameter network with N accessible ports. Defining a normalized complex echo signal spectrum $E_n(j\omega)$ at port n such that the spectral power density equals the echo area of the target at radian frequency ω, $E_n(S)$ is the Laplace transform of the target impulse response at the n-th aspect and polarization. Equating $E_n(S)$ to the corresponding diagonal element of the network scattering matrix, one concludes that it can be factored as

$$E_n(S) = \frac{F_n(S)}{K(S)} \quad . \tag{1}$$

The complex zeros of K(S) correspond to poles of the target. The K-pulse of a target is defined as the inverse transform of K(S), a

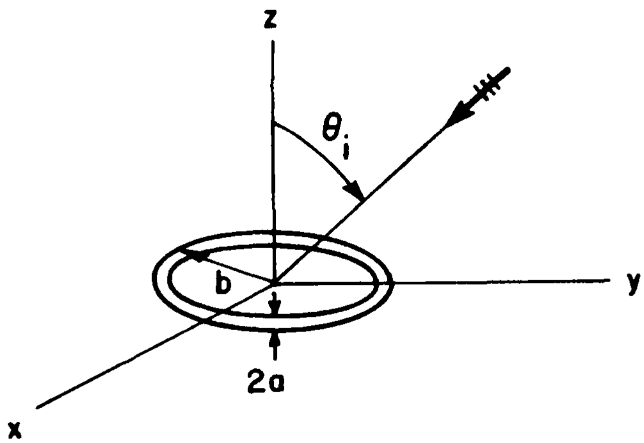


FIG. 1

Figure 1. Plane wave scattering from a thin circular loop

time-limited (TL) waveform of excitation which produce excitation-dependant TL waveforms of response for all N aspects and polarizations considered.

A thin conducting circular loop exhibits strong resonances as an antenna or scatterer. For such an object, K-pulse illumination should be particularly effective in obtaining a TL response. Using the concept of a characteristic radar signal waveform for a target which produces TL response at a large number of aspects, Kennaugh [1] obtained a simple K-pulse waveform for a perfectly conducting wire. In this paper, the approach proposed by Gerst and Diamond [2] to obtain special input waveforms to produce finite duration outputs and reduce intersymbol interference in communication systems is employed to derive an approximate K-pulse for a thin conducting circular loop.

II. ANALYSIS AND NUMERICAL RESULTS

Consider a thin conducting circular loop illuminated by an incident plane wave. The loop is located in the x-y plane, and the plane wave is incident in the y-z plane and the angle θ_i is measured from the $\hat{z}$-axis. The geometry of the problem is illustrated in Figure 1.

From reference [3], it can be shown that the backscattered field for a thin circular loop can be expressed as

$$E_{\phi}^{s} \sim -jkz_{o} \frac{e^{-jkr}(\pi b)^{2}}{4\pi r} \sum_{n=\infty}^{\infty} \frac{j^{2n+2}\left[J_{n+1}(kb \sin\theta_{i}) - J_{n-1}(kb \sin\theta_{i})\right]^{2}}{Z_{nn}} \quad . \tag{2}$$

$$E_{\theta}^{s} \sim \pi^{2} b \; kbZ_{o} \cos^{2}\theta_{i} \frac{e^{-jkr}}{4\pi r} \sum_{n=-\infty}^{\infty} \frac{(-1)^{n}\left[J_{n+1}(kb \sin\theta_{i}) + J_{n-1}(kb \sin\theta_{i})\right]^{2}}{Z_{nn}} \quad . \tag{3}$$

where

$$Z_{nn} = \frac{j\pi Z_{o} \; kb}{2} \left[K_{n-1} + K_{n+1} - 2\left(\frac{n}{kb}\right)^{2} K_{n}\right] \quad , \tag{4}$$

and

$$K_{n} = \frac{1}{2\pi} \int_{0}^{2\pi} \frac{e^{-jkb\sqrt{4\sin^{2}(\phi/2) + (a/b)^{2}}}}{\sqrt{4\sin^{2}(\phi/2) + (a/b)^{2}}} e^{-jn\phi} d\phi \quad . \tag{5}$$

Note that the K_n are the usual Fourier coefficients and can be efficiently evaluated using the fast Fourier transform technique.

A. IMPULSE RESPONSE

The fast Fourier transform technique is also utilized to obtain the backscattered impulse response waveforms of a thin conducting circular loop. The impulse response waveforms for several incidence angles for both parallel and perpendicular polarizations are calculated. The response waveforms of Figures 2 and 3 were obtained by Fourier synthesis of an incident wave which approaches closely an impulse wave, i.e.,

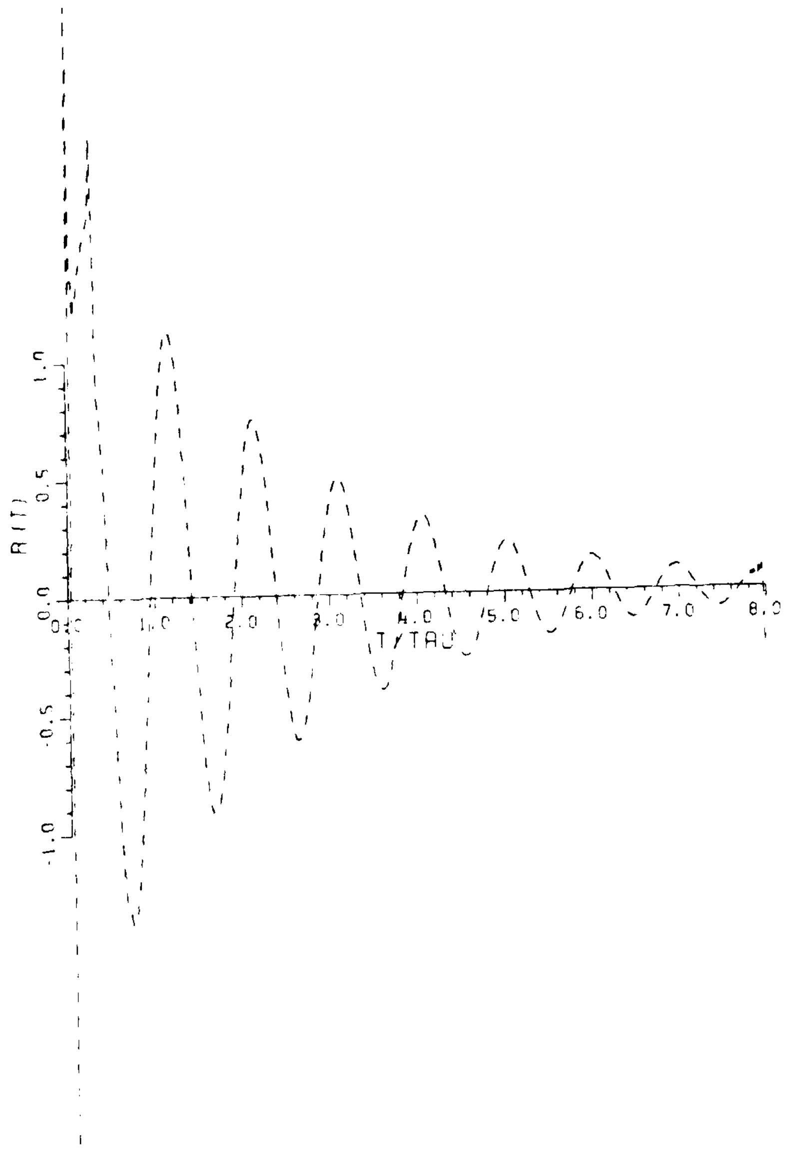
$$e^{i}(t) = \begin{cases} \dfrac{1}{2\Delta}\left(1 + \cos\dfrac{\pi t}{\Delta}\right); & -\Delta < t < \Delta \\ 0 & \text{otherwise} \end{cases} \quad . \tag{6}$$

In the calculation,

$$\Delta = \frac{2\pi}{N\omega_o} \quad , \tag{7}$$

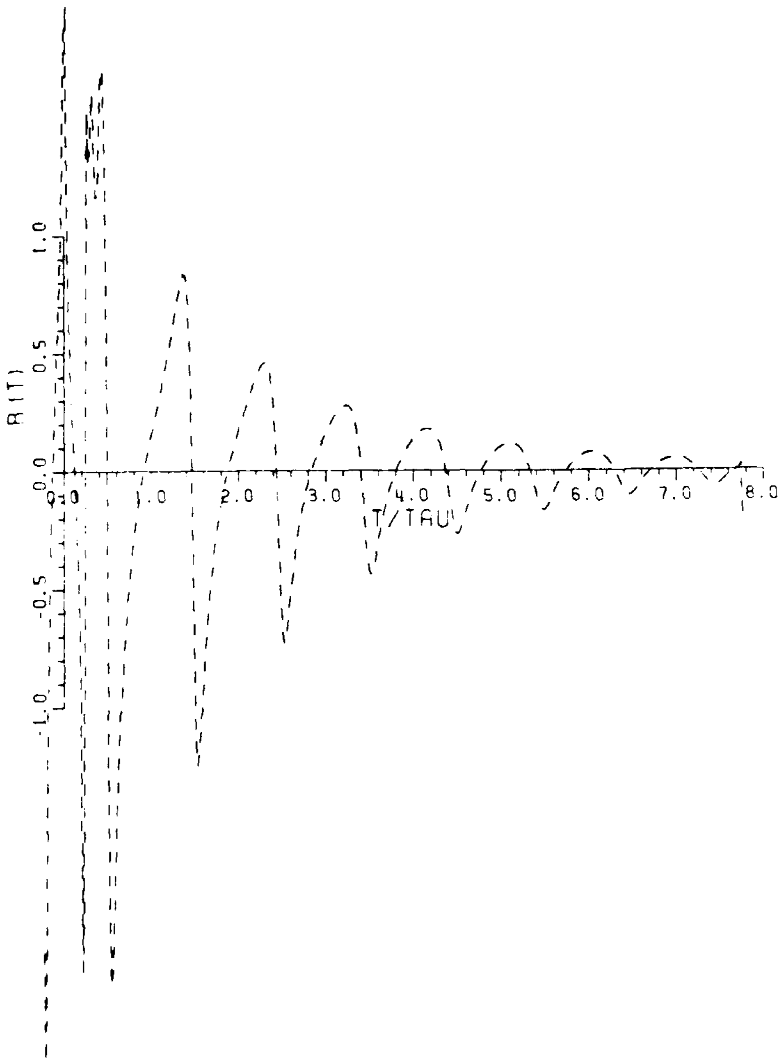
where $N\omega_o$ is the window size used for the spectrum. The values of E_ϕ^s and E_θ^s at N frequencies were calculated using Equations (2) and (3). The impulse response waveforms for a $\hat{\phi}$-polarized incidences wave are presented in Figure 2 and that for a $\hat{\theta}$-polarized incident wave is presented in Figure 3. Note that t=0 is the time of arrival at the center of the loop.

It is seen from Figures 2 and 3 that the strong resonance associated with the thin circular loop is manifested in a persistent



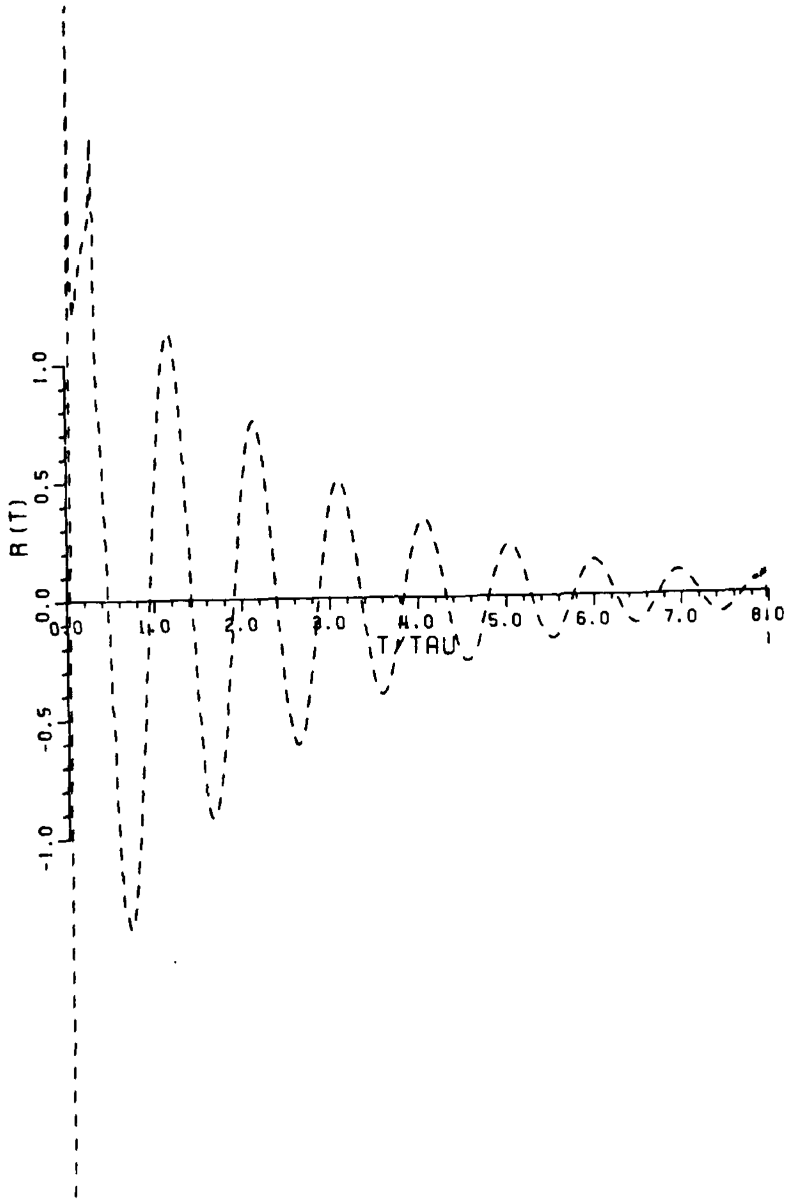
(a)

Figure 2. Impulse response waveforms for backscattering by a thin circular loop ($\hat{\phi}$-polarized incidence)



(b)

Figure 2. Continued



(c)

Figure 2. Continued

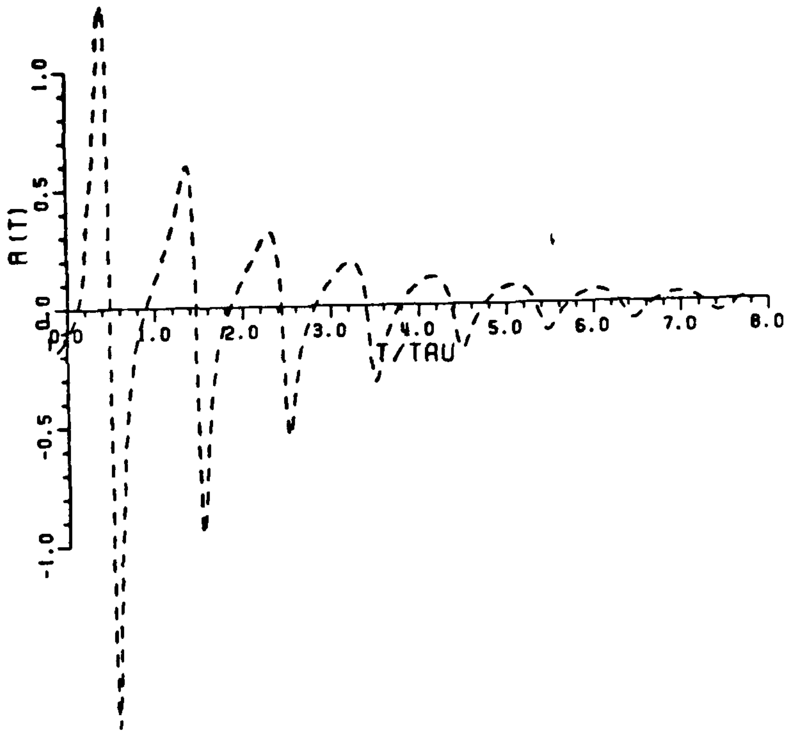


Figure 3. Impulse response waveform for backscattering by a thin circular loop ($\hat{\theta}$-polarized incidence)

ringing. It is of interest to note that in the late time, the impulse response waveform has a period of $t = \frac{2\pi b}{v}$, where $2\pi b$ is the circumference of the circular loop and v is the effective velocity along the circular loop.

B. THE K-PULSE RESPONSE

Using the pole-elimination concept employed by Gerst and Diamond [2], a special imput waveform, the approximate K-pulse K(s), has been obtained for the thin conducting circular loop:

$$K(S) = \frac{1 - e^{-\varepsilon S}}{S} \prod_{n=1}^{N} 1 - e^{-\varepsilon(S-S_n)} , \qquad (8)$$

where ε is an arbitrary positive number and S_n are the natural frequencies of the circular loop. It has been shown [2] that K(S) is a finite Laplace transform of length $(n+1)\varepsilon$.

The first string of dominant poles for a thin conducting circular loop has been found by seeking the roots of $Z_{nn} = 0$ via the Newton-Raphson method. Table I lists the numerical values for the first 30-pairs of poles for the loop with $b/a = \pi \times 10^{-3}$.

Setting the length of the K-pulse to be $(n + 1)\varepsilon = \tau$, and using the first 30-pairs of poles, the approximate K-pulse input waveform K(t) has been calculated from Equation (8) using Fourier synthesis. The resultant K(t) is presented in Figure 4.

To verify that this input signal effectively terminates the

TABLE I

Natural Frequencies of Thin Conducting Circular Loop

$a/b = \pi\ 10^{-3}$

	$\sigma_n b/c \pm j\omega_n b/c$	
N= 1	(-0.0672581	1.0359231)
N= 2	(-0.0964985	2.0485101)
N= 3	(-0.1186274	3.0575323)
N= 4	(-0.1372346	4.0649166)
N= 5	(-0.1536496	5.0713091)
N= 6	(-0.1685334	6.0770230)
N= 7	(-0.1822732	7.0822301)
N= 8	(-0.1951137	8.0870428)
N= 9	(-0.2072286	9.0915375)
N= 10	(-0.2187373	10.0957670)
N= 11	(-0.2297340	11.0997734)
N= 12	(-0.2402861	12.1035872)
N= 13	(-0.2504538	13.1072321)
N= 14	(-0.2602777	14.1107254)
N= 15	(-0.2698004	15.1140881)
N= 16	(-0.2790437	16.1173306)
N= 17	(-0.2880441	17.1204643)
N= 18	(-0.2968164	18.1234989)
N= 19	(-0.3053838	19.1264439)
N= 20	(-0.3137568	20.1293049)
N= 21	(-0.3219558	21.1320896)
N= 22	(-0.3259889	22.1348019)
N= 23	(-0.3378740	23.1374474)
N= 24	(-0.3456107	24.1400299)
N= 25	(-0.3532205	25.1425571)
N= 26	(-0.3606989	26.1450233)
N= 27	(-0.3680624	27.1474400)
N= 28	(-0.3753089	28.1498127)
N= 29	(-0.3824559	29.1521358)
N= 30	(-0.3894980	30.1544094)

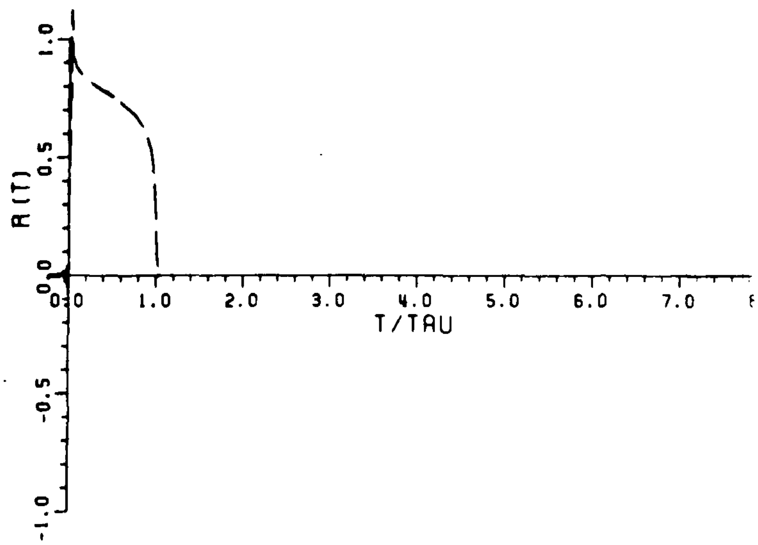
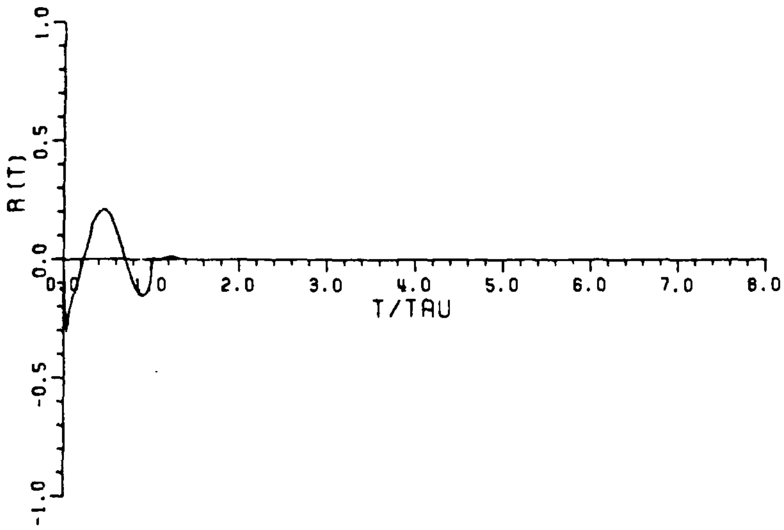


Figure 4. Approximate K-pulse for a thin conducting circular loop

oscillatory response of the circular loop as a scatterer, several examples were calculated. Using frequency weightings of K(S), the transient response corresponding to the examples shown in Figures 2 and 3 were synthesized. The results are presented in Figures 5 and 6. When the K-pulse shown in Figure 4 is the time variation of electric field intensity in an incident plant wave striking the loop at broadside, i.e., $\theta_i = 0°$, the resultant time variation of the backscattered field at a great distance is that shown in Figure 5a. It can be seen that the response signal is essentially zero for $t/\tau > 1$. For a $\hat{\phi}$-polarized incident plane wave striking the loop at $\theta_i = 45°$ or $\theta_i = 90°$, the K-pulse response waveforms are that shown in Figures 5b and 5c respectively. It is interesting to observe that for the incident plane wave striking the loop at θ_i, the response waveform is essentially zero for $t/\tau > 2b/c \sin\theta_i$. Finally, the K-pulse response waveform for a $\hat{\Theta}$-polarized incident wave ($\theta_i = 45°$) is shown in Figure 6. Again, it is seen that the K-pulse input signal effectively terminates the oscillatory response of the loop (see Figure 4).

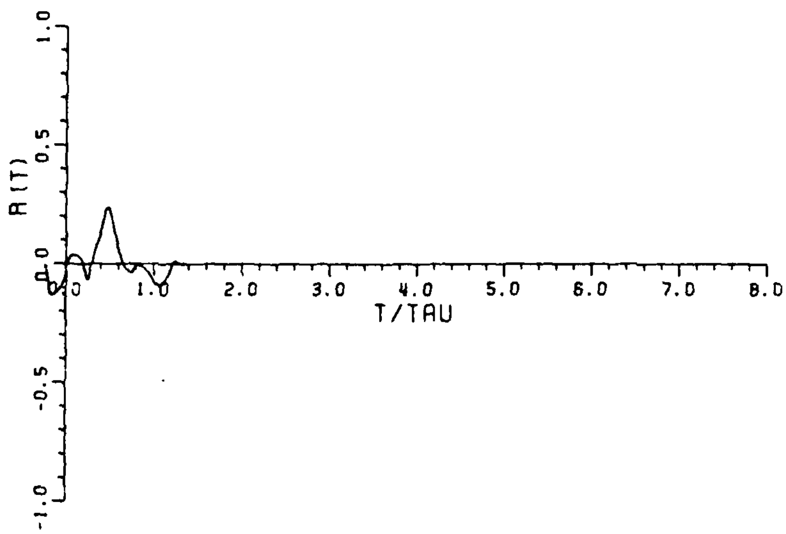
III. CONCLUSION

Based on the pole elimination concept, a time-limited, aspect-invariant, input waveform of minimal duration, the K-pulse, is obtained for a thin conducting circular loop. The resultant response waveforms are also found to be time-limited. Therefore, by employing the K-pulse input waveform, the resonant ringing associated with the circular loop has been eliminated. We should also observe that Gerst



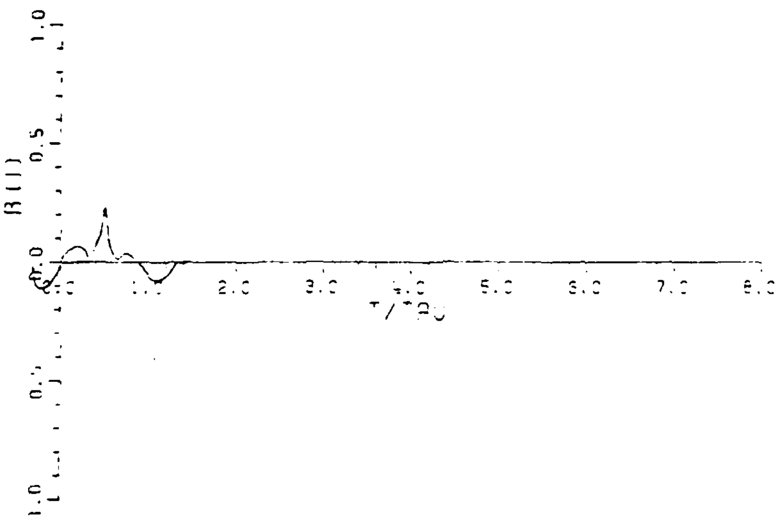
(a)

Figure 5. K-pulse response waveforms for $\hat{\phi}$-polarized incident plane wave



(b)

Figure 5. Continued



(c)

Figure 5. Continued

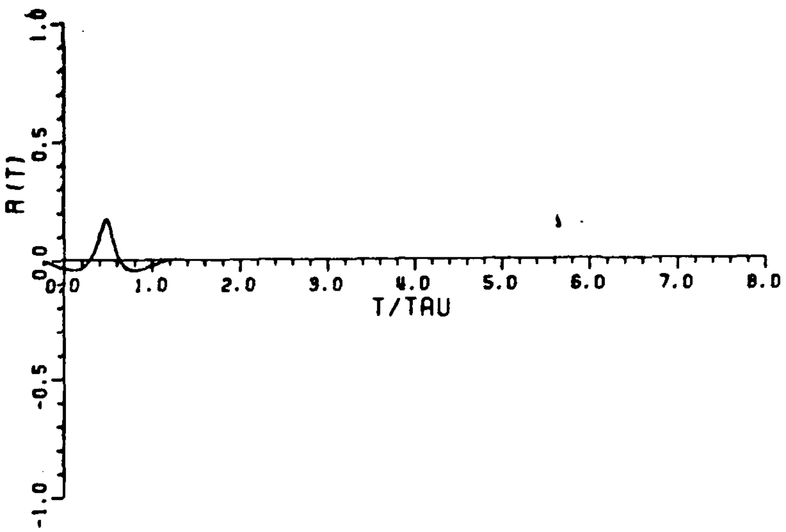


Figure 6. K-pulse response waveforms for $\hat{\theta}$-polarized incident plane wave

and Diamond's pole elimination concept [2] was actually for a lumped parameter system and ε in Equation (8) of this paper was arbitrary. For the loop, a distributed parameter system, ε is not arbitrary. Properly the K-pulse for a lumped parameter system ($\varepsilon \to 0$) is a singularity.

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[2] I. Gerst and J. Diamond, "The Elimination of Intersymbol Interference by Input Signal Shaping," Proc. IRE Vol. 19, No. 7, pp. 1195-1203, 1961.

[3] R.F. Harrington, "Field Computation by Moment Methods," Chapter 5.

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